Space Qualification of Optoelectronic and Photonic Devices

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Purpose

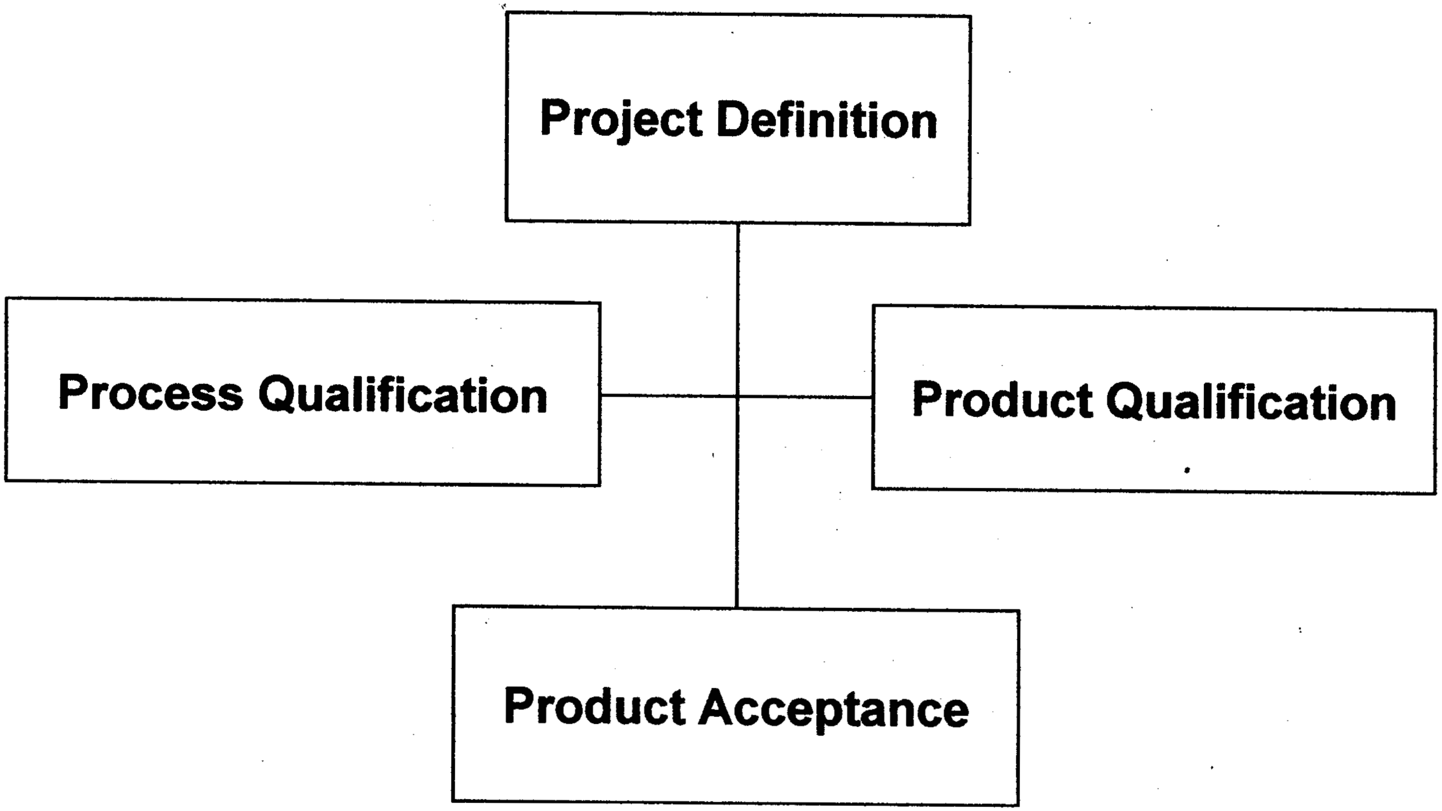
NASA

- Establish a guideline for a space qualification plan of newly developed optoelectronic devices,
- Identify the advantages of the newly developed devices over the existing state-of-the-art photonic devices,
- Accelerate the readiness of the technology to space programs, and
- Disseminate realistic qualification models of the device selection to the NASA community.

Presentation outline

- Purpose
- Qualification Methodology
- General-Optical Communications
- Light Sources*
- Modulators/Waveguides/Fibers
- Receivers*
- Failures Modes: Power/Temperature
- Space Qualification Plan
- Conclusions

Methodology: Space Qualification of Optoelectronic and Photonic Devices



Space Qualification Plan

- This plan covers the general guidelines for photonic devices intended for use in space craft and critical ground-support equipment applications.
- The part number shall consist of the number of this specification followed by the detail specification slash number and applicable dash numbers.
- The photonic devices shall be the parts used in space optical communication system, such as:
  - laser diodes (single/multiple modes)
  - PIN receiver diodes and transistors
  - fibers (single/multiple mode)
  - Index guided: p-InP/n-InGaAs/p-InP
  - Opto-couplers
  - Optical amplifiers
  - Optical switches
- Major critical variables to qualify the laser are:
  - Lifetimes
  - Operating Temperature (100 °C,10° C/half life): τ= exe (E_a / kT)
  - Bias Current/Voltage
  - Output power
  - Data Rates: 50Mb/s
  - Spectral width

Mars Surveyor

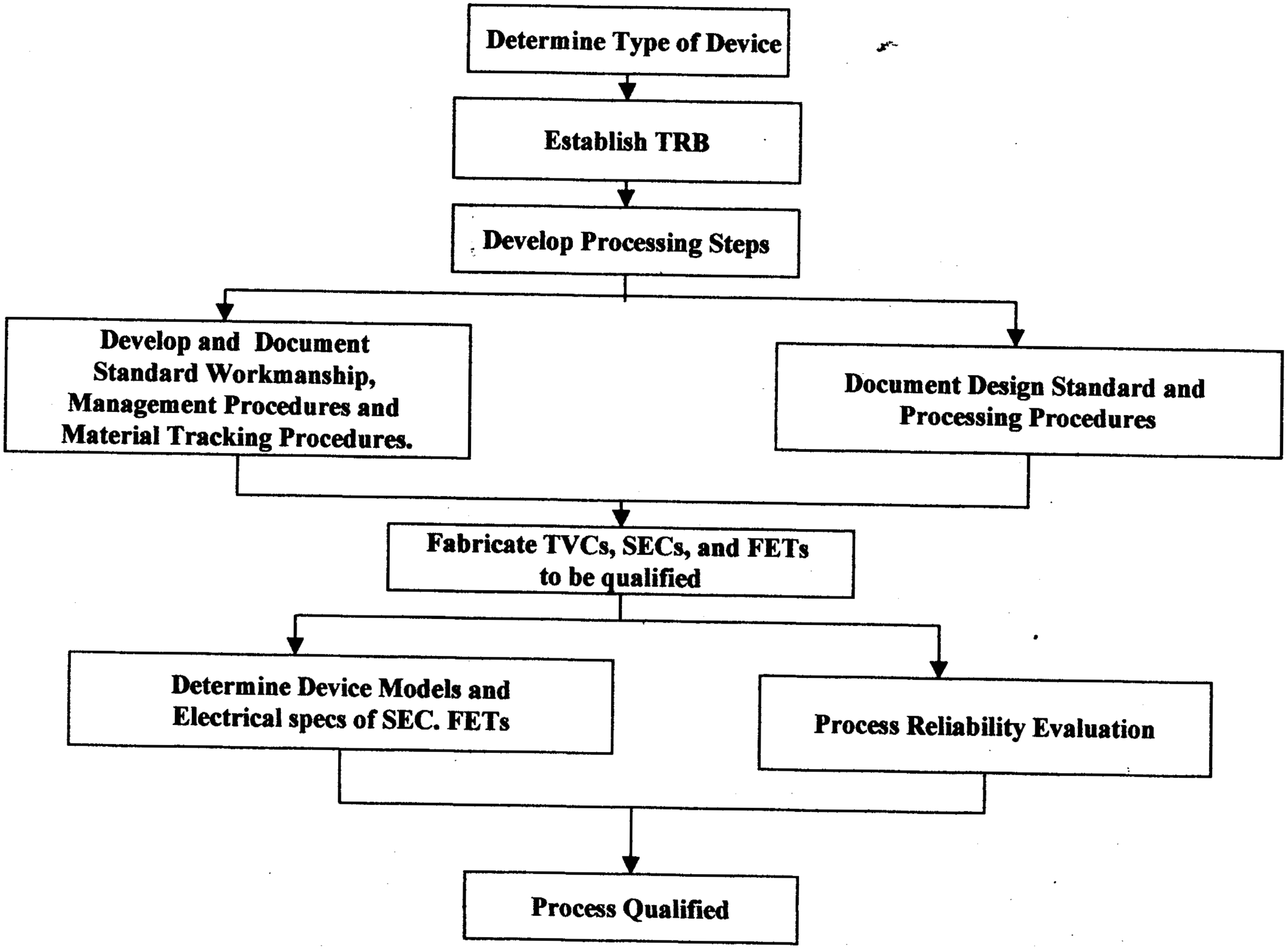
- No Safety no Science (Rocks, Water. Etc)

- Geoid, Season, Location and time of entry
  - Surface Pressure <10.6 mbar for solar panel opening
  - Elevation = 3Km
  - Lifetime = 90 days

- Needs Spatial Thermal Data
  - Infrared Thermal Mapper (IRTM)
  - Mars Orbiter Laser Altimeter (MOLA)
  - Mars Orbiter Camera (MOC)
  - 20 years Old Viking Data

Mission	Mars Surveyor
Landing Site	3N - 12S 20Km diameter
Reflectivity	>0.07
Slope	<4 Degrees
Fine Component Inertia	>5 - 6 cgs
Rock Abundance	5 - 10 %
Red/Volet	<2.0 (0.090-0.120/0.058-0.065)

Process Qualification



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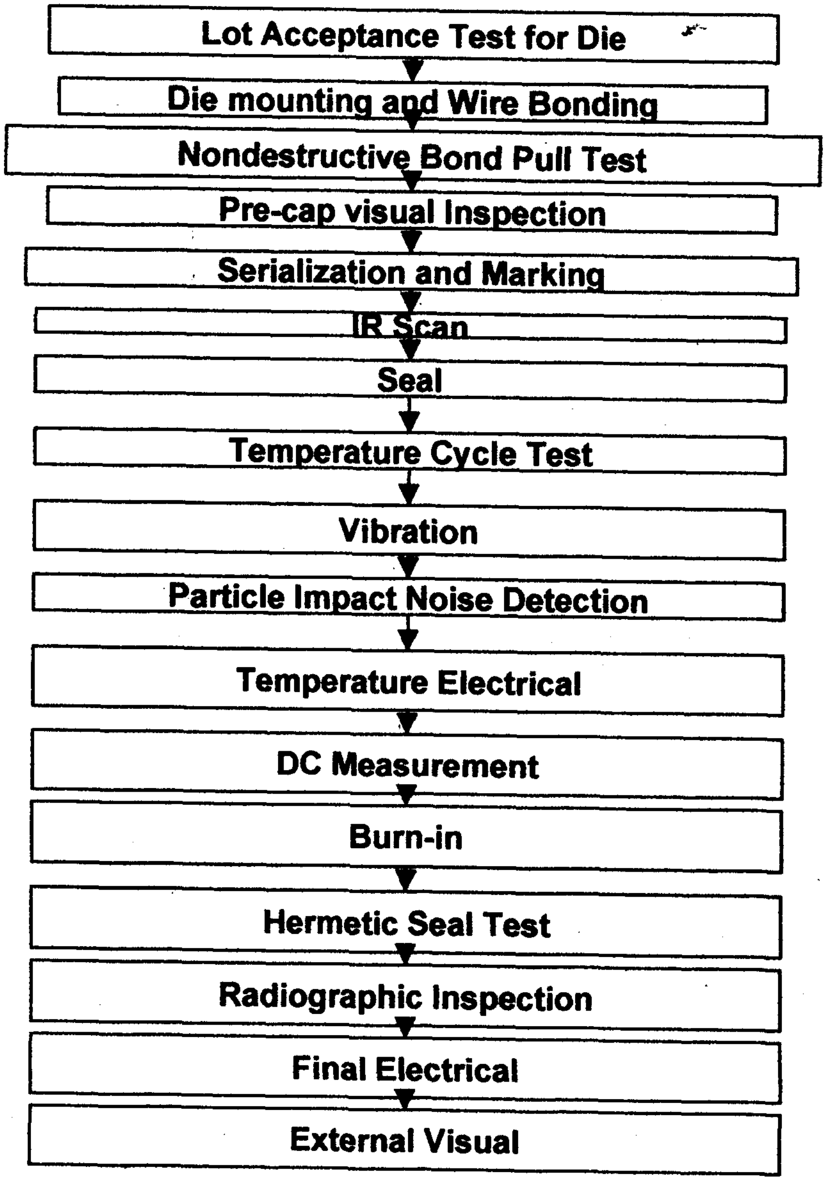
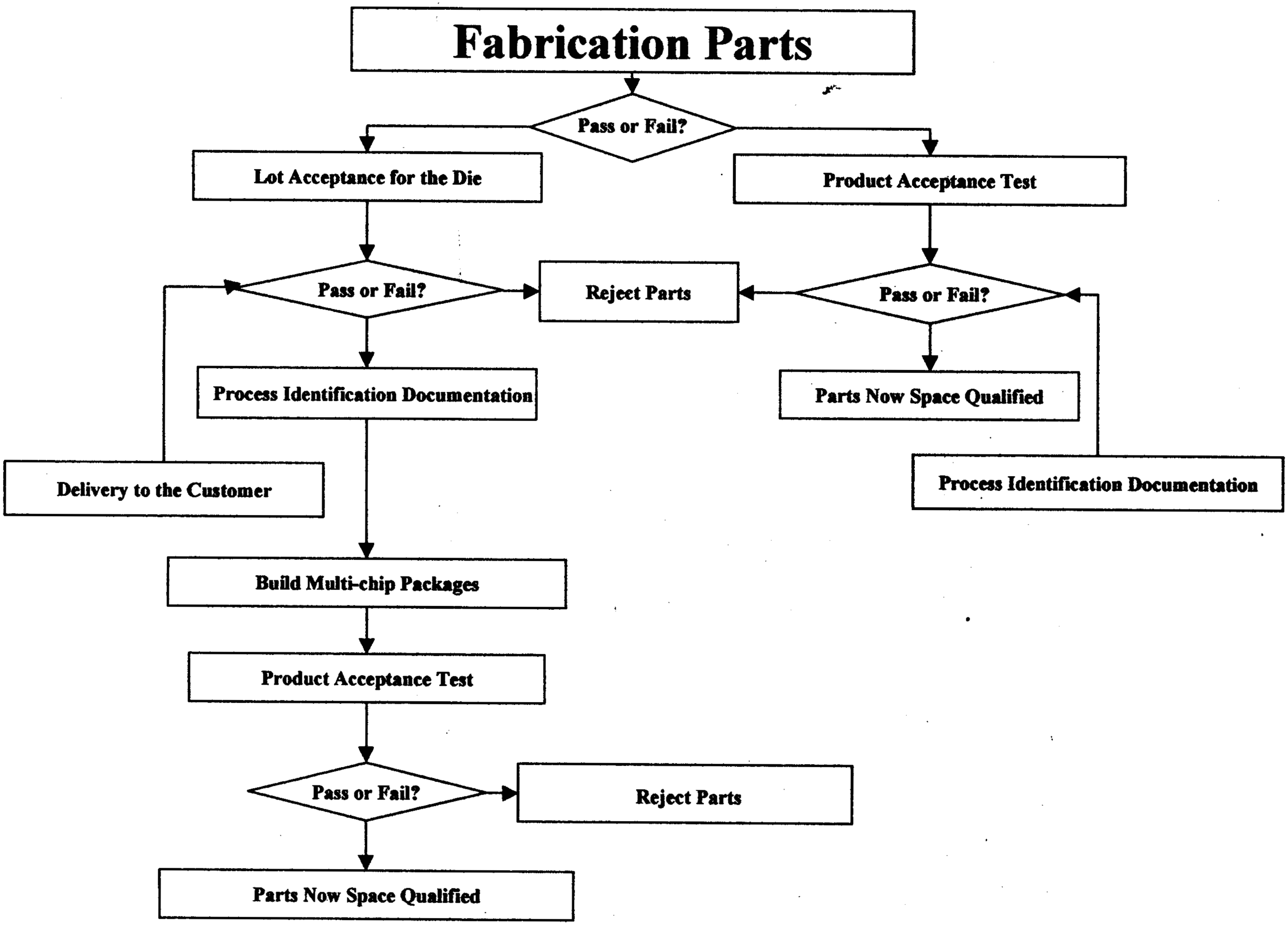
Screening Process for Product Acceptance



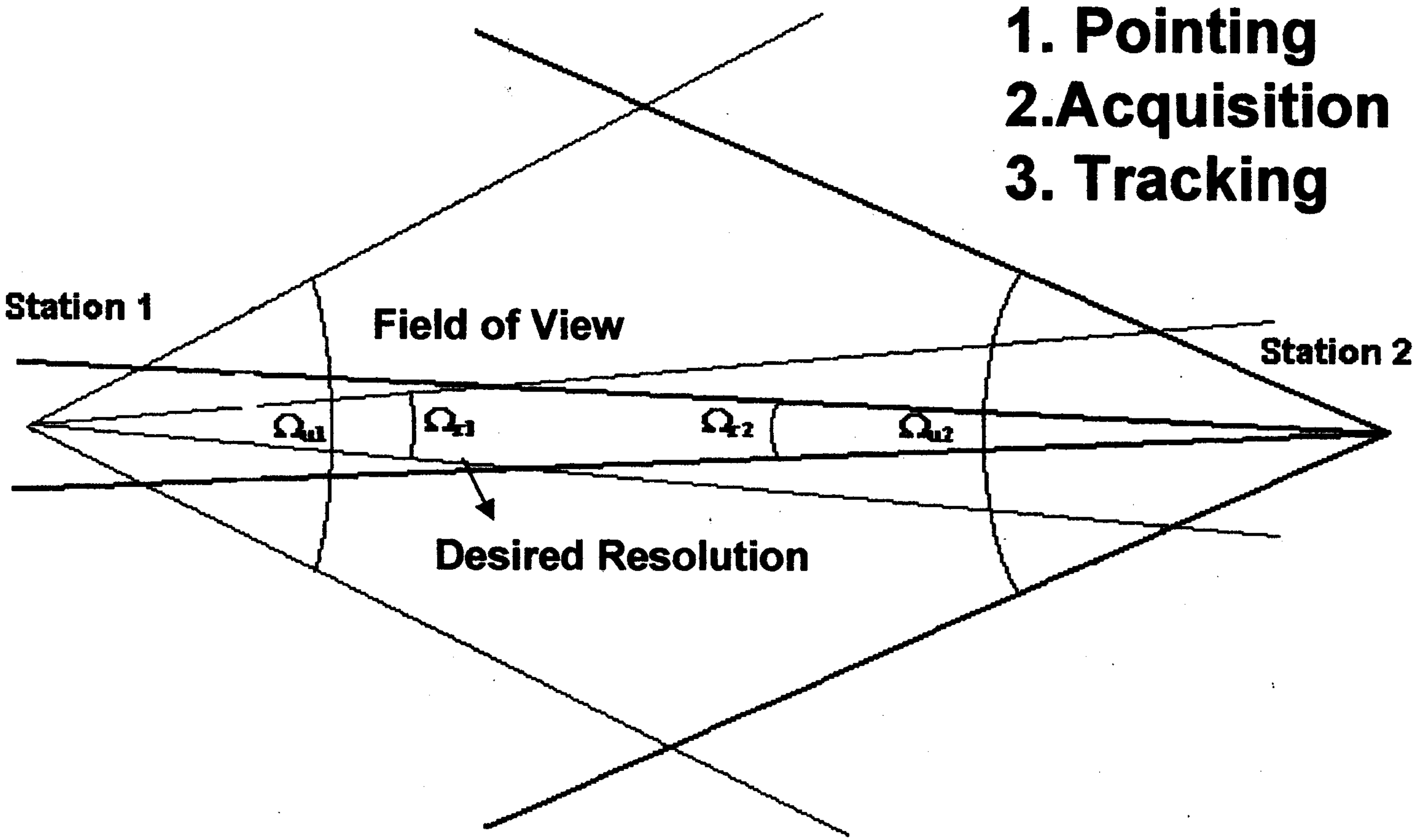

Fabrication Parts
Pass or Fail?
Lot Acceptance for the Die
Product Acceptance Test
Pass or Fail?
Reject Parts
Pass or Fail?
Process Identification Documentation
Parts Now Space Qualified
Delivery to the Customer
Process Identification Documentation
Build Multi-chip Packages
Product Acceptance Test
Pass or Fail?
Reject Parts
Parts Now Space Qualified

Optical Communications

- Potential increase in modulation bandwidth (10^5 x RF)
- The ability to concentrate power in extremely narrow beams
- Significant reduction in component size

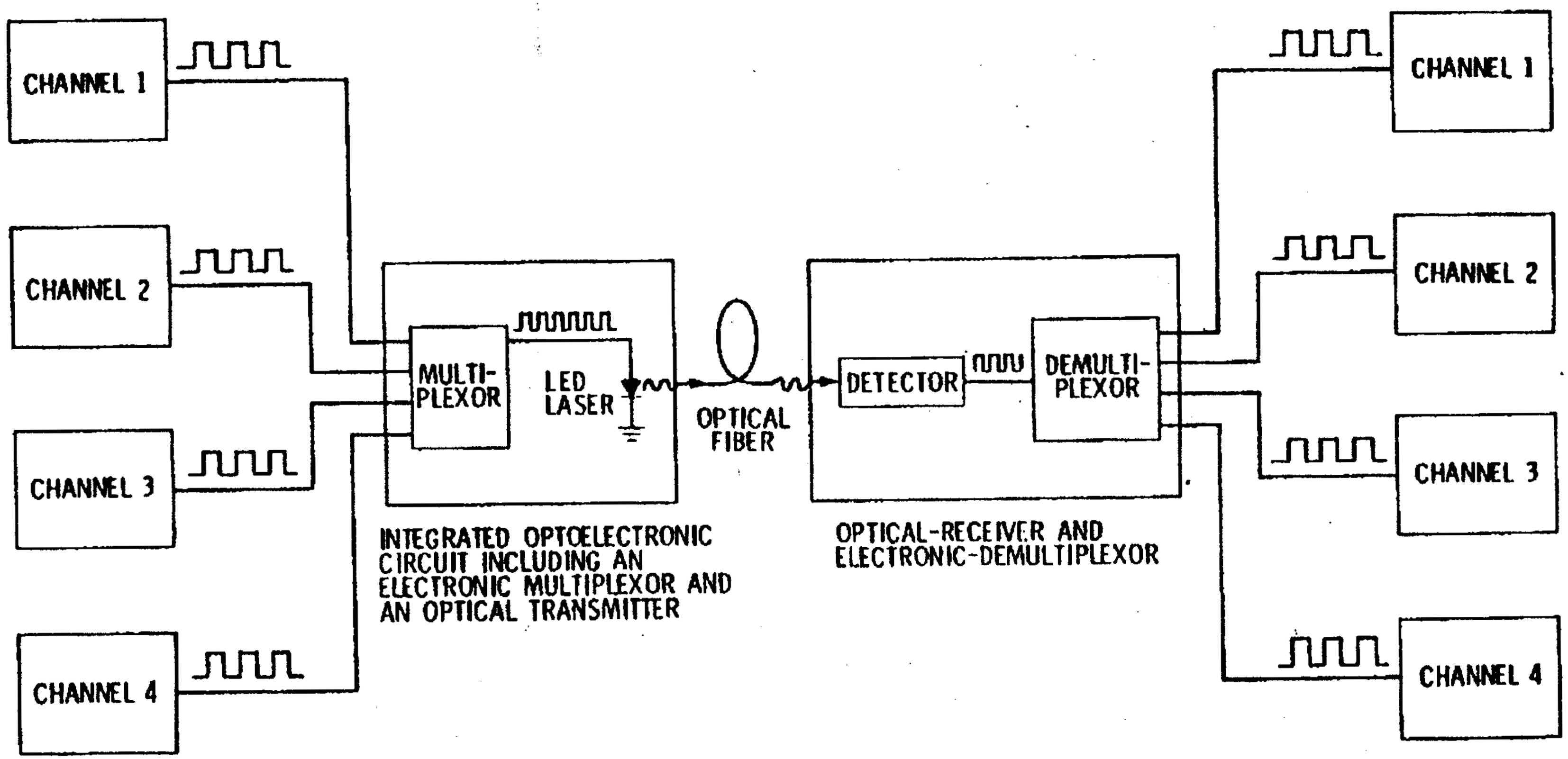
Space Optics

1. Pointing
2. Acquisition
3. Tracking

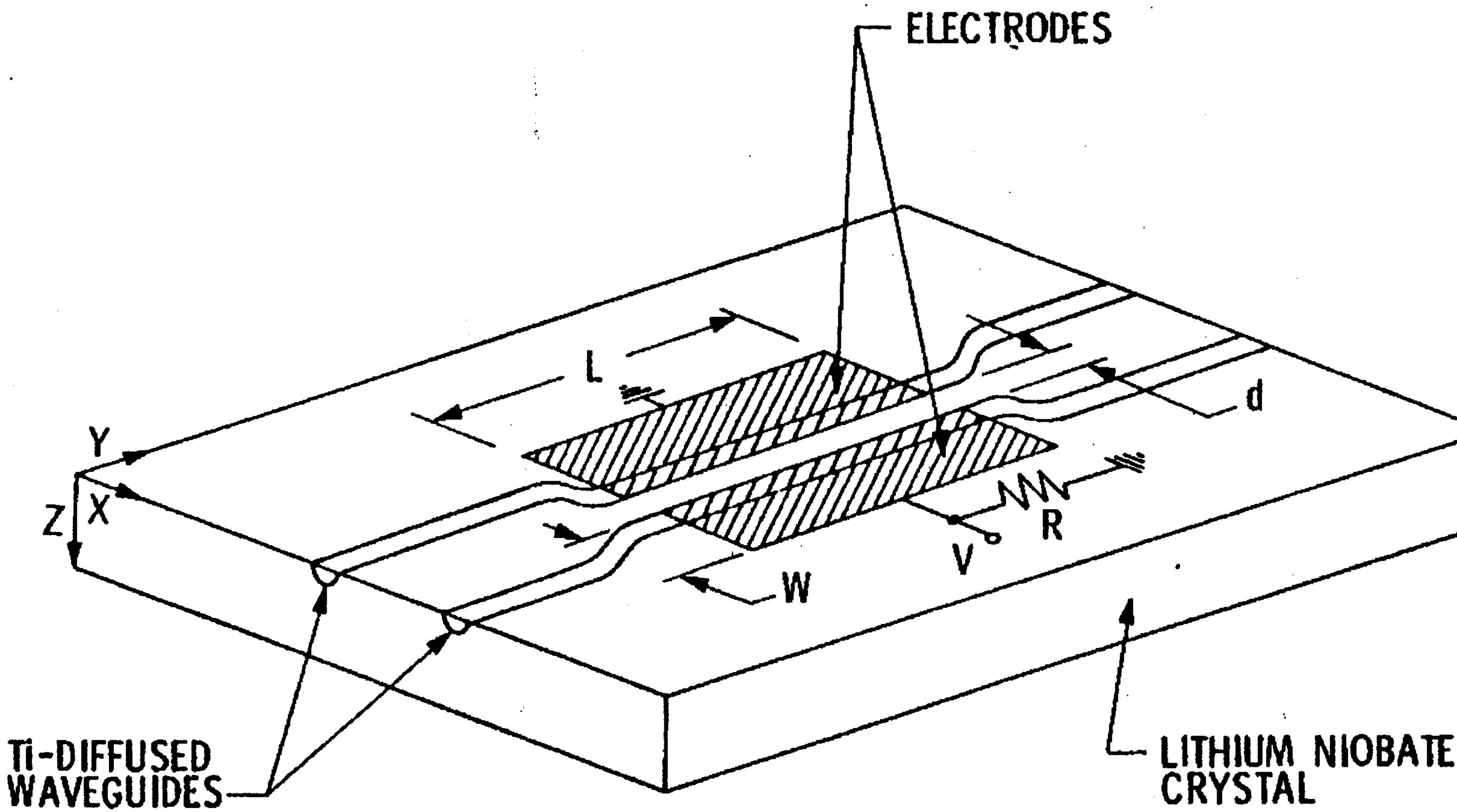


Two-way Acquisition Geometry

Integrated Optoelectric Communication System

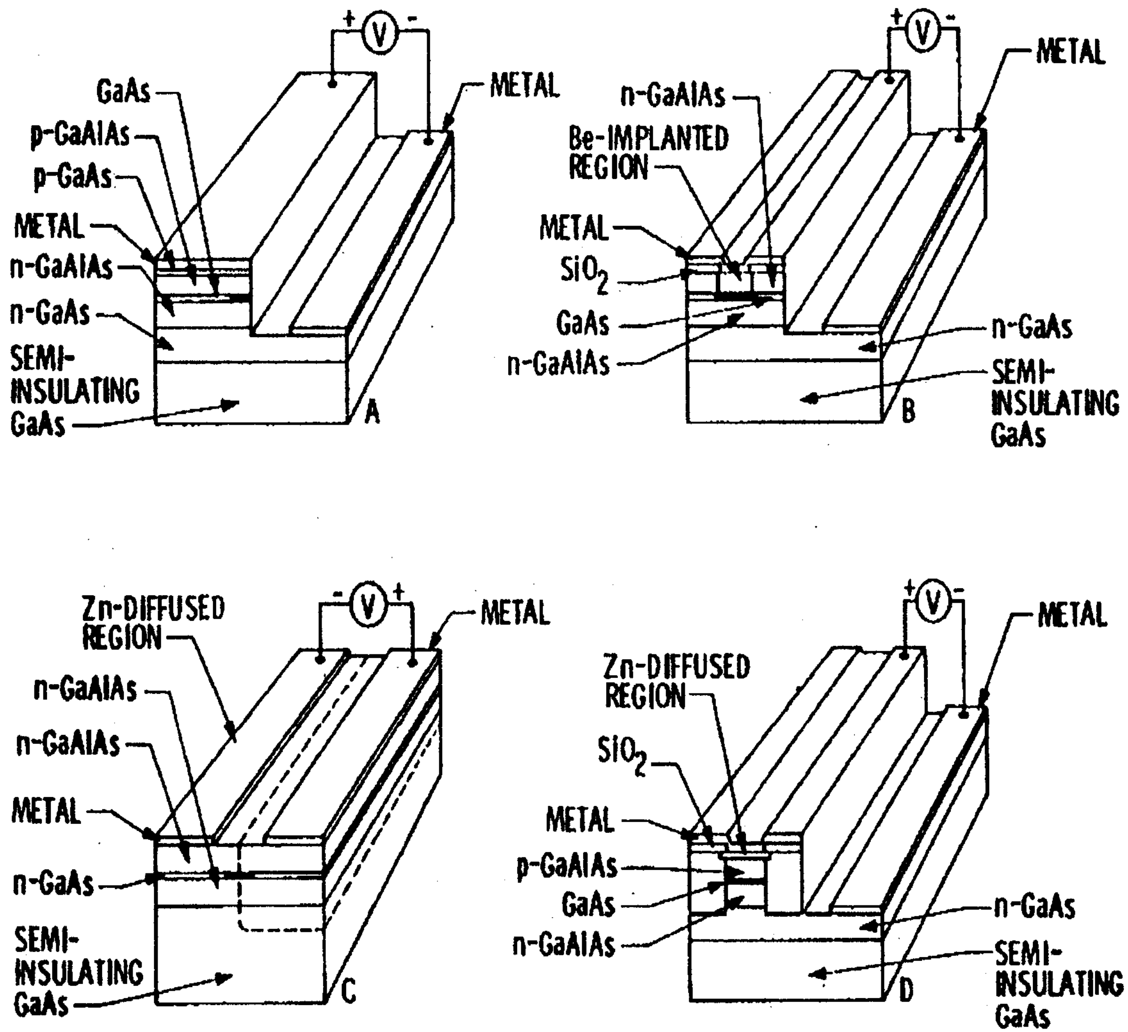


High Speed Directional coupler Modulator

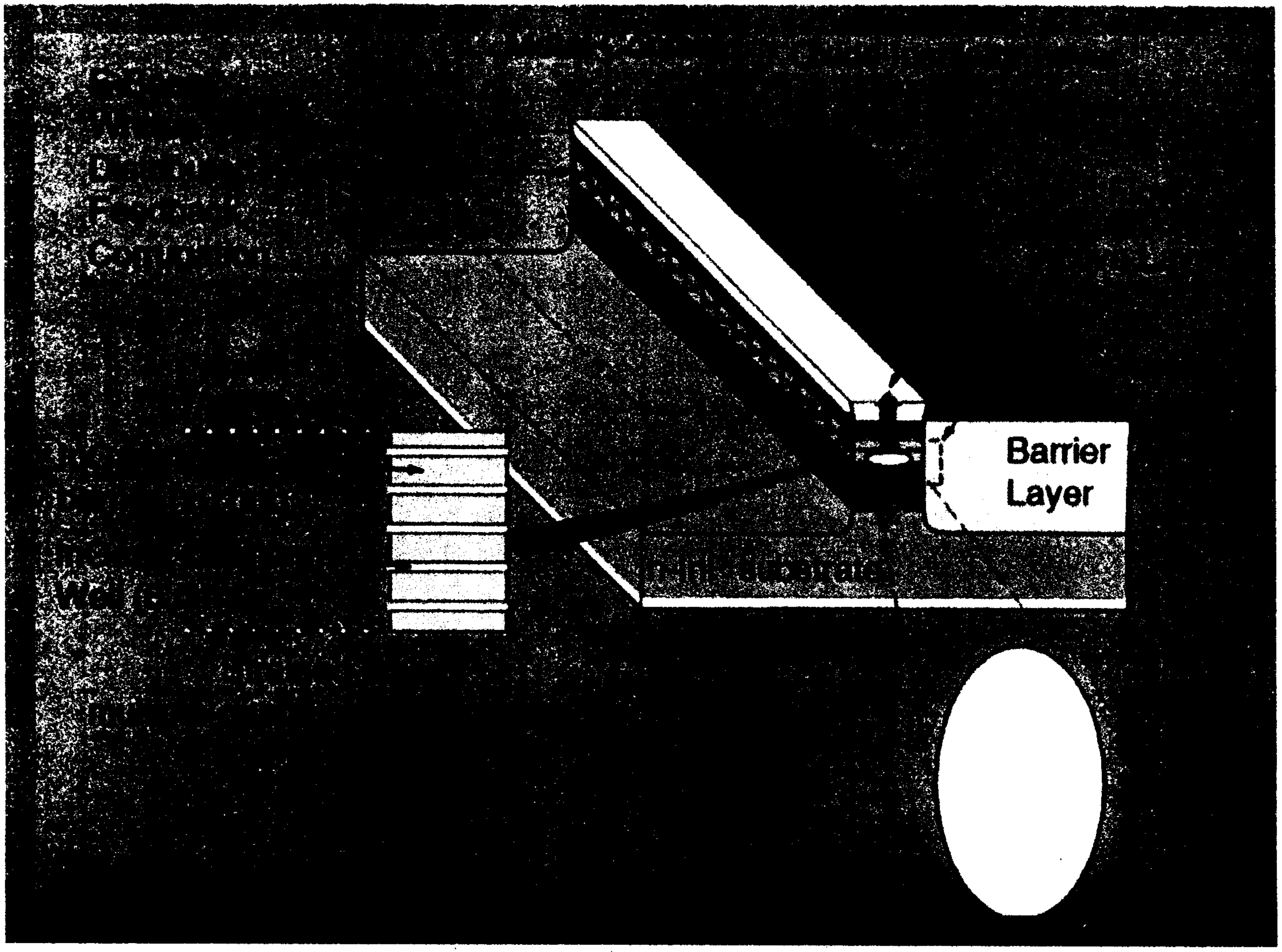


Integrated Circuits on a Semi-insulating Substrate

A). Each has two metal contacts on top for connecting to a voltage source
B). Beryllium-implanted region
C). Zinc-diffused region
D). Buried heterostructure.



A Typical Laser Diode



Al-Free InGaAsP Diode Laser by Gas Source MBE

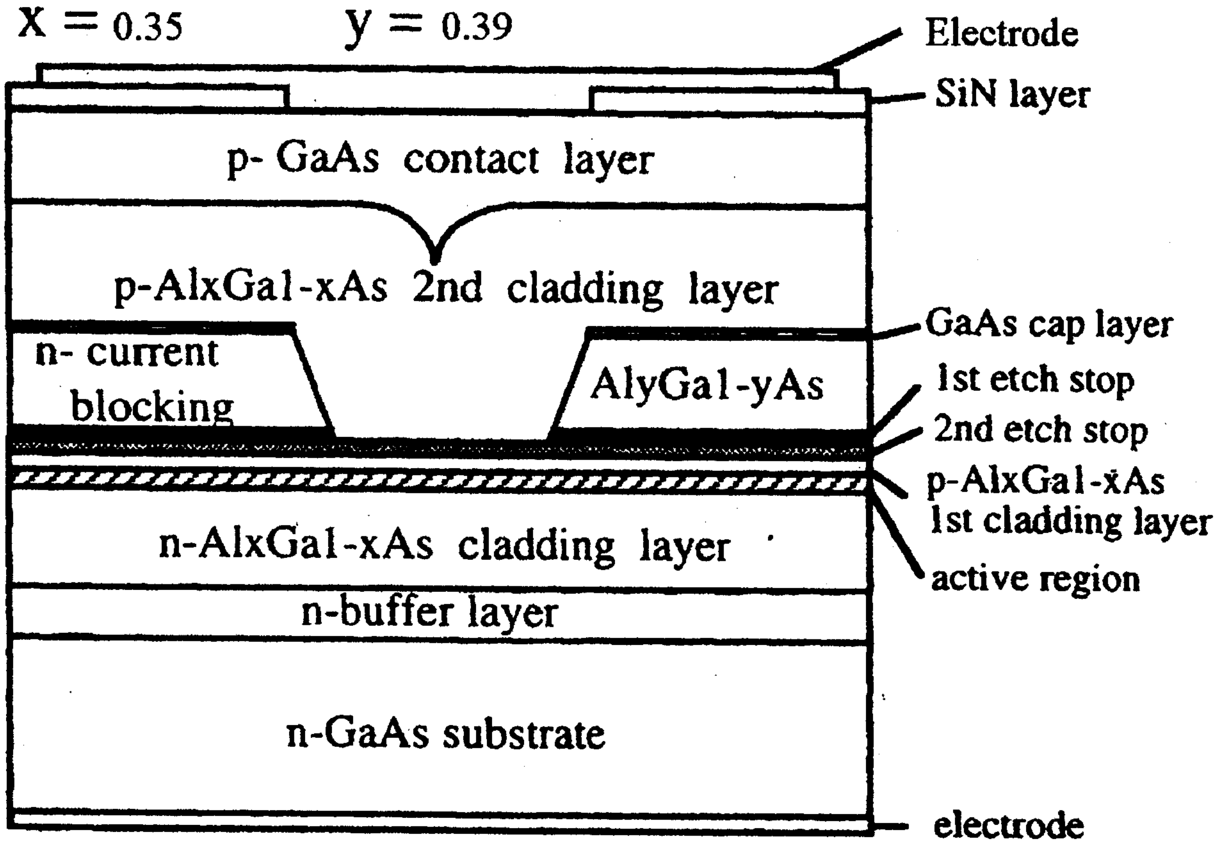
Barrier Bandgap, eV	1.82
Waveguide Thickness,	0.4
QW thickness, A	300
Tranverse Far-Field	31.5
Conversion Efficiency, % @L=1mm	64
Jth Acm-2 @ L=1mm	644
Wavelength, nm	807

- **High Growth Rate**
- **Low Growth Temperature**
- **Superior Optical Quality (α = 1.5 cm^{-1})**

Buried-Stripe Type 980nm Laser Diodes

- **Weakly Indexed Guided Structure ($\Delta n_e = 3.6 \times 10^{-3}$)**
- **Single TE Mode**
- **550mW at 25°C**
- **α = 7.4 cm^{-1}**
- **η_i = 92.4 %**
- **ESD No Significant LI or IV change at - 30 ~ 12KV stress**
  - » **C = 100pF**
  - » **R = 1.5KΩ**
- **Degradation 3X10^{-6}/hour at 50°C and 250mW**

H. Horie et.al,
SPIE, Vol 3945, 2000



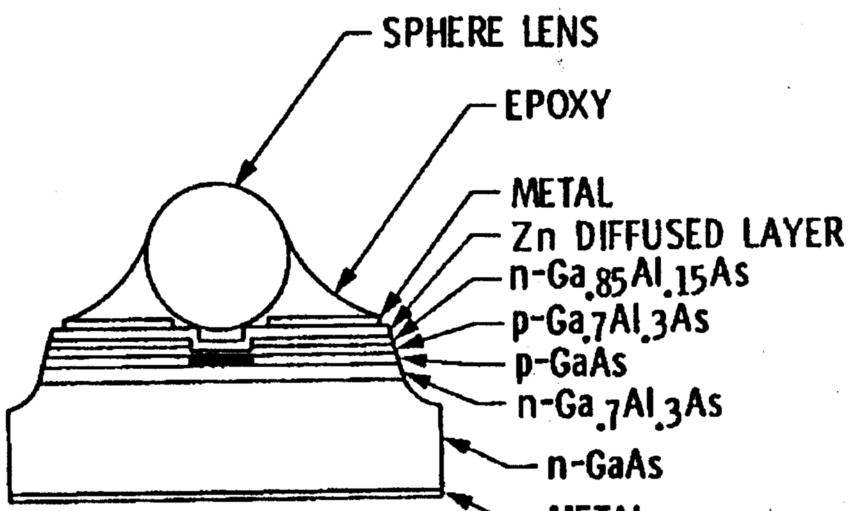
State-of-the-art Optical Sources

Device	Material	Wavelength (microns)	Power (mW)	Bandwidth (MHz)	Coupling Power*(mw)	Life Time (hr)
LED						
	AlGaAs	0.75 - 0.9	2	50	0.1	1.00E+08
	InGaASP	1.3	2	50	0.1	1.00E+08
LD						
	AlGaAs	0.8-0.9	3.0-5.0	1000	1	1.00E+06
	InGaAsP	1.3	3.0-5.0	1000	1	>10e4
	InGaAsP	1.6				

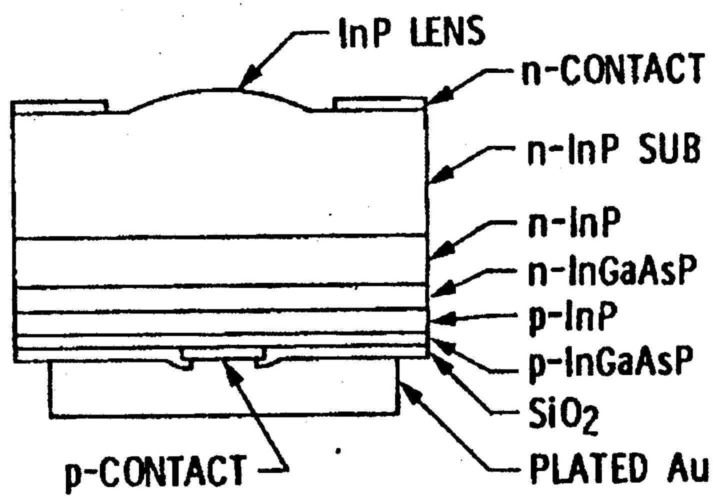
Key Qualification Variables

- Surface Degradations
- Facet oxidation/slow
- Aluminum/inhibit diffusion: AlGaAs/GaAs
- Output power: 200mW
- Catastrophic optical damage/fast
- Facet melting: AlGaAs>InGaAs/InP
- Bandgap shrinking: non-absorbing mirror (<0.1 MW/cm^2)
- Alloy electrodes
- Metal diffusion
- AuZnNi: Dark spot defects
- Schottky type electrode: TiPtAu
- Bonding parts
- Soft solders: In, Sn, and Au rich solders/sudden failures
- Hard solders: Au rich solders/reduce instability
- Optical degradation/Modes
- Dislocations
- Metal diffusion
- Oxidation
- Inner material Degradations
- Point Defects
- Crystal structures vacancies
- AlGaAs/GaAs>InGaAs(P)/InP
- Quality of the Crystal
- 110 Crystal axis
- Impurity level of the material
- Workmanship/reproducibility
- Radiation Damages
- Total Ionizing Dose (25K Rad)
- Replacement Damage (>25K Rad)
- Single Event Upsets (75MeV/mg/cm^2)
- Single Event Latch ups
- Single Event Burn outs

Typical Structure of Light Emitting Diodes



(a)

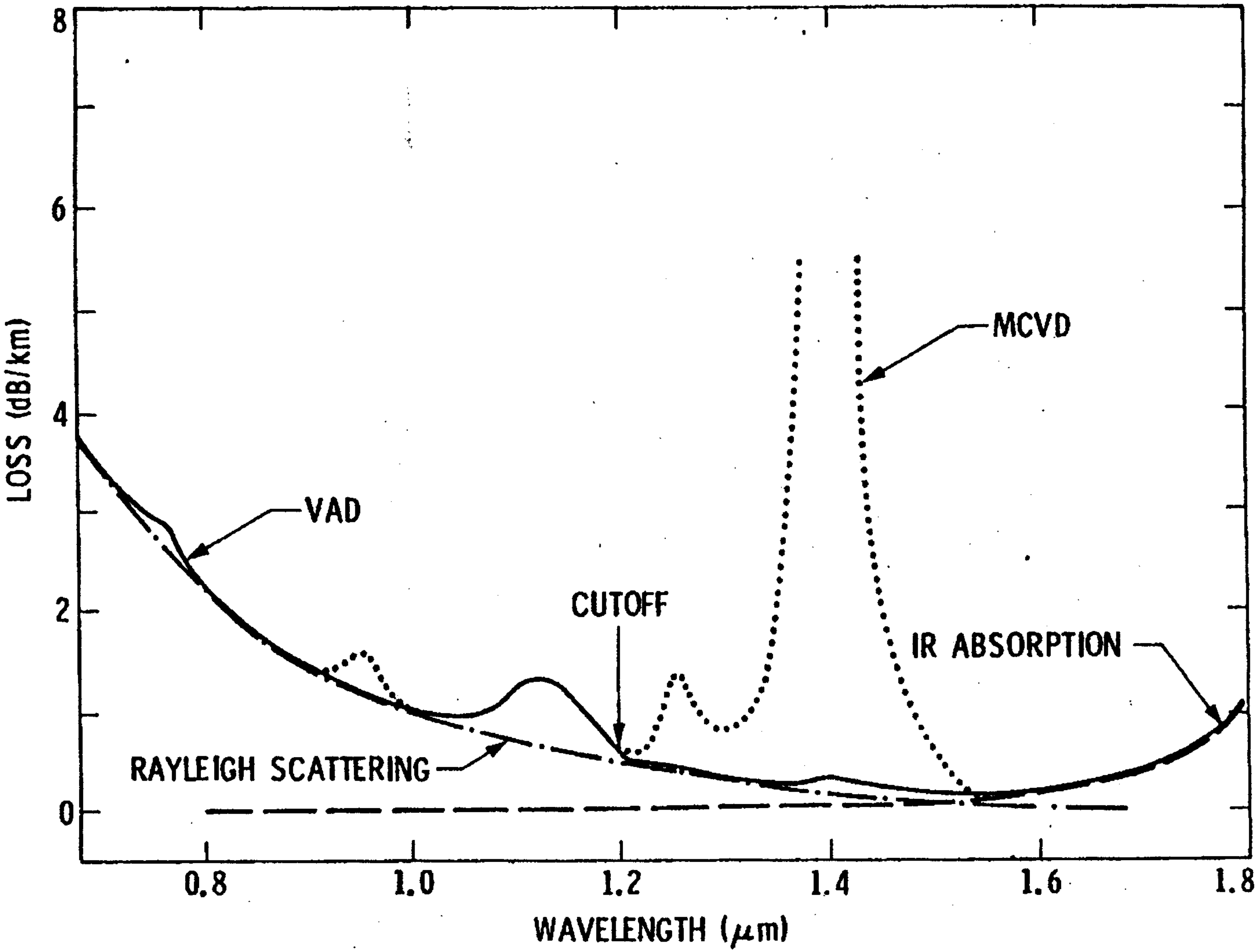


(b)

AlGaAs LED

InGaAsP LED

Typical Loss in Optical Fibers



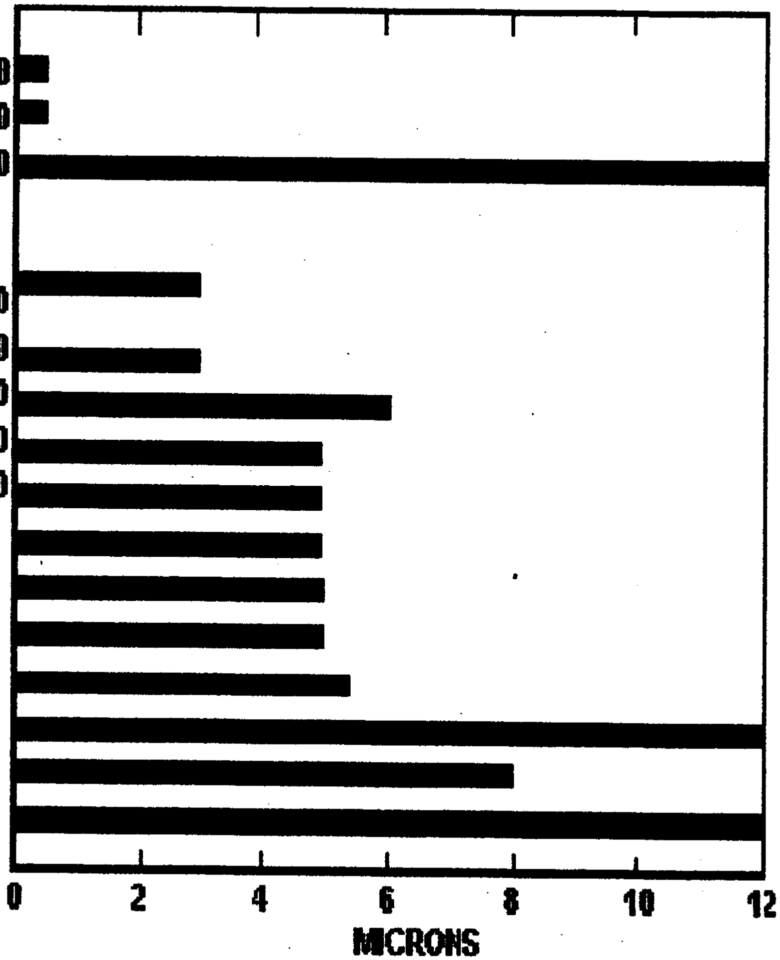
Comparison of VAD and MCVD Fibers

		VAD		MCVD	
Dimension of perform	type max.	10-20 km more than 100 km		2-5 km about 10 krii	
Speed of synthesis	typ- max,	0.4-0.7 g/min. 2-3 g/min. possible		0.1-0.3 g/min. 0.5-1.0 g/min.	
Characteristics					
minimum loss	(dB/km)	multi-mode	single-mode	multi-mode	single-mode
	0.85 microns	2.1	1.9	2.1	1.9
	1.3 microns	0.4	0.4	0.5	0.4
	1.55 microns	0.22	0.2	0.3	0.2
0-H ion conc.		less than 1 ppb		less than 10 ppb	
band width	typ. max.	0.5-1.0 GHz*km 6.7 GHz*km		0.8-1.2 GHz*km 3.5 GHz*km	

Classifications of Detectors

MATERIAL	TECHNOLOGY	T(K)
Si (INTRINSIC)	MONOLITHIC	300
GaAs (INTRINSIC)	MONOLITHIC	300
PYRO (LiNbO3, TGS)	HYBRID	300
PbS	PULSE - BIASED Z-PACKAGED	190
HCT	HYBRID	160
PbSe	PULSE - BIASED	120
HCT	Z-PACKAGED	120
HCT	HYBRID	120
HCT	MONOLITHIC	77
Pt/Si SCHOTTKY	MONOLITHIC	77
InAsSb	HYBRID	77
InSb	HYBRID/MONO	77
HCT	HYBRID	40
Si:In	MONO/SOXS	40
Si:Ga, Si:Bi	MONO.SOXS	18

SPECTRAL RANGE



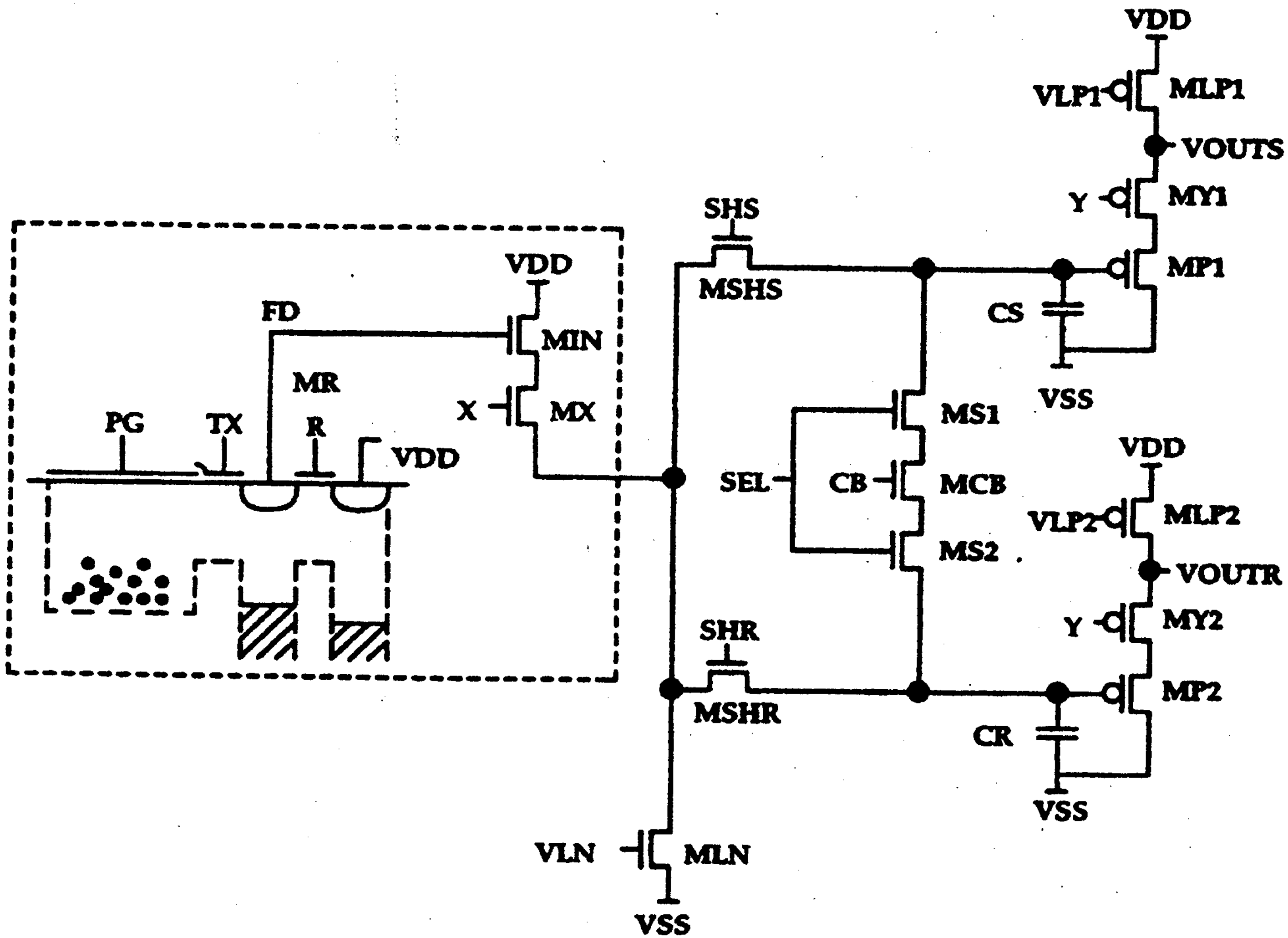
Current Focal Plane Materials, Temperatures, and characteristics

PHOTON EFFECTS		**THERMAL EFFECTS**	**ELECTROMAGNETIC EFFECTS**
EXTERNAL	**INTERNAL**		
PHOTOCATHODES:	**PHOTOCONDUCTIVE:**	**BOLOMETERS:**	**HETERODYNE DETECTION**
CONVENTIONAL NEGATIVE ELECT. AFFINITY	INTRINSIC EXTRINSIC	THERMISTORS METAL SUPERCONDUCTOR SUPERINDUCTOR CRYOGENIC SEMICONDUCTOR	**JOSEPHSON JUNCTION**
GAIN MECHANISMS:	**PHOTOVOLTAIC:**		**METAL-METAL OXIDE-METAL**
GAS AVALANCHE MULTIPLIERS CHAN. ELECT. MULTIPLIERS	P-N JUNCTION AVALANCHE DIODE P-I-N DIODE SCHOTTKY DIODE HETEROJUNCTION GRADED JUNCTION	**PYROELECTRIC**	
	PHOTOELECTROMAGNETIC	**THERMOELECTRIC**	
	PHOTOTRANSISTORS	**GOLAY CELL**	
	PHOTON DRAG		
	HOT ELECTRON BOLOMETER		

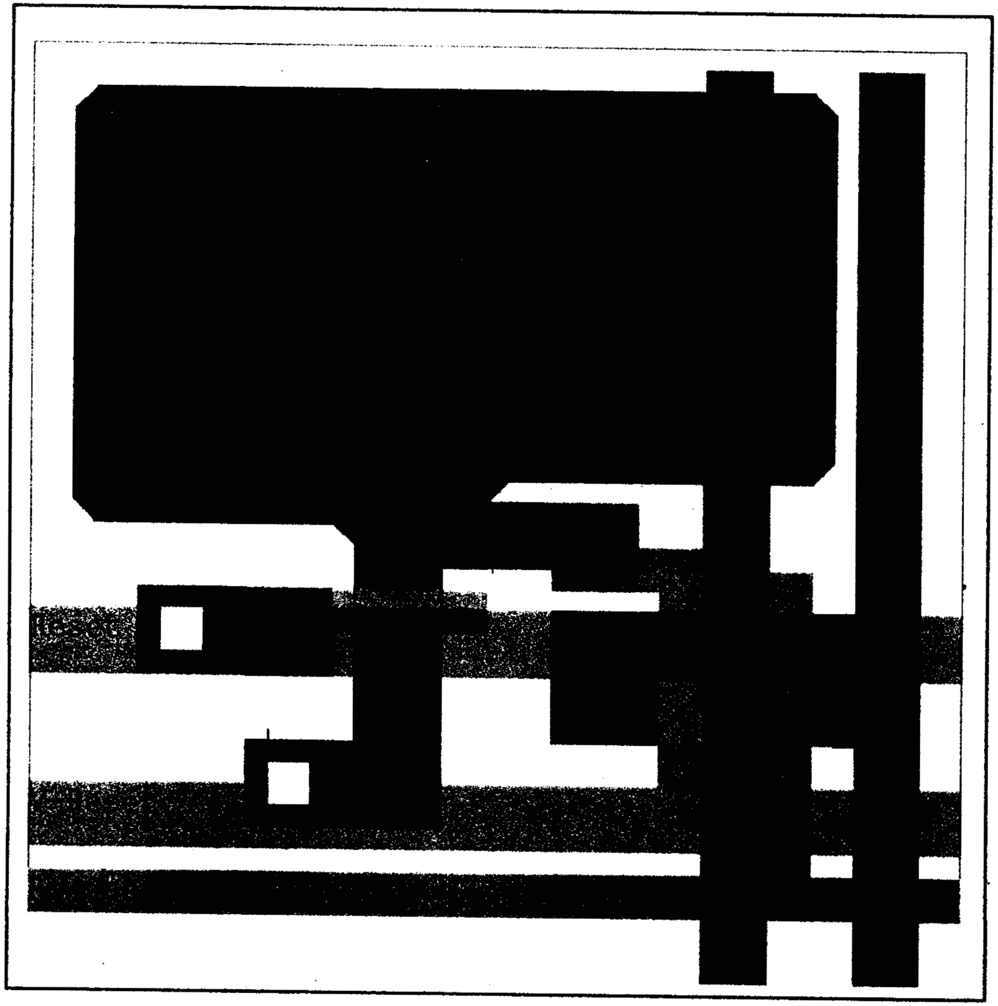
The State-of-the-Art Detectors

	Si APD	Ge-APD	InGaA/InP APD	InGaAs-PD/FET
λ (microns)	0.5-1.0	0.8 - 1.5	1.25	1.0 -1.7
η max	0.8	0.8	0.8	0.8
i d (A)	1.00E-11	1.00E-06	1.00E-09	1.00E-09
Cj (pF)	1	1	1	2
F	300	70	30	
τ_r (ns)	0.15		0.16	0.06

Active Pixel Sensor (APS)
Single Stage Buried Channel Junction CCD



Active Pixel Sensor

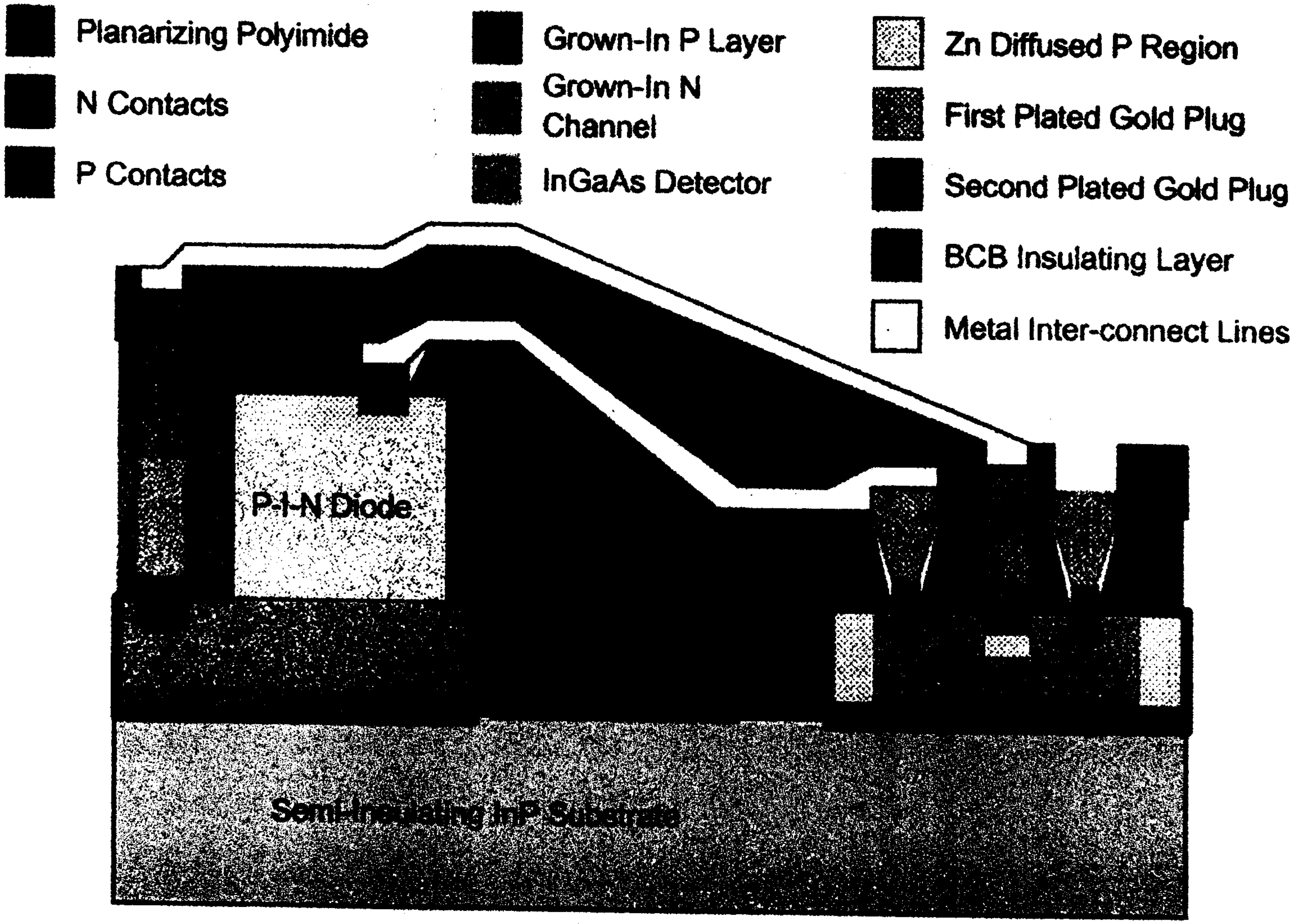


APS vs. CCD

PARAMETERS	APS	CCD
Format	Wafer Scale (8")	4096/4096(1")
Voltage	3.3 Volts	+/- 20Volts
System Power	0.05W	10W
On-Chip Imaging	Yes	None
Window Readout	Yes	None
On-Chip Addressing	12 bits	None
Pixel Size	5 microns	5 microns
Process	0.25 micron CMOS	0.8 micron CCD
Fill Factor	25%	25%
Conversion Gain	10 V/e-	10 V/e-
Saturation	100,000 e-	60,000 e-
Input Ref. Noise	20 e-	10 e-
Dynamic Range	74 dB	75 dB
Peak QE	30%	25%

- Retains the high performance of CCD
- No need high charge transfer efficiency
- CMOS technology allows highly integrated on-chip electronics
- System power/mass reduction of the order of 1000x/100x
- Lower cost large format image sensors
- Enables highly miniaturized imaging camera instrument design
- Creating new markets in multimedia and information superhighway Applications (video phone, teleconferencing, document imaging: dental x-rays, mammography, toys, baby monitors)

A Typical Monolithic Integration



Conclusions

General overview of Optoelectronic and Photonic Devices for space optical communications was described. Efforts were concentrated to generate the needed general guideline of the reliability concerns for potential applications in space Missions. Ultimate goal for this effort is to gradually establish enough data to develop a space qualification plan of newly developed specific parts. using a numerical model to assess the lifetime and degradation of the devices hopefully for potential long term optical communications in space missions.

The good news for the optoelectronic and photonic devices is that this technology is developing very rapidly. The bad news from our reliability perspective is that there are no faster, better, and inexpensive qualification methodology for these devices in space applications without participating to the manufacturer as early as possible.

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